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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No.	97-2301
First Inventor or Application Identifier	RIOJA
Title	ALUMINUM-COPPER-MAGNESIUM
Express Mail Label No.	EH 423664208 US

APPLICATION ELEMENTS
See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. [X] * Fee Transmittal Form (e.g., PTO/SB/17) (Submit an original and a duplicate for fee processing)
2. [X] Specification [Total Pages 20] (preferred arrangement set forth below)
   - Descriptive title of the Invention
   - Cross References to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to Microfiche Appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings (if filed)
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
3. [X] Drawing(s) (35 U.S.C. 113) [Total Sheets 10]
4. Oath or Declaration [Total Pages 30]
   a. [ ] Newly executed (original or copy)
   b. [ ] Copy from a prior application (37 C.F.R. § 1.63(d)) (for continuation/divisional with Box 17 completed) [Note Box 5 below]
      i. [ ] DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).
5. [ ] Incorporation By Reference (useable if Box 4b is checked) The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered to be part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
6. [ ] Microfiche Computer Program (Appendix)
7. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
   a. [ ] Computer Readable Copy
   b. [ ] Paper Copy (identical to computer copy)
   c. [ ] Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

8. [ ] Assignment Papers (cover sheet & document(s))
9. [ ] 37 C.F.R.§3.73(b) Statement (when there is an assignee) [ ] Power of Attorney
10. [ ] English Translation Document (if applicable)
11. [X] Information Disclosure Statement (IDS)/PTO-1449 [X] Copies of IDS Citations
12. [ ] Preliminary Amendment
13. [X] Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
14. [ ] * Small Entity Statement(s) (PTO/SB/09-12) [ ] Statement filed in prior application, Status still proper and desired
15. [ ] Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. [X] Other: UNSIGNED DECLARATION

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17. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:
[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No: ______/______
Prior application information: Examiner ______ Group / Art Unit: ______

18. CORRESPONDENCE ADDRESS

[ ] Customer Number or Bar Code Label (Insert Customer No. or Attach bar code label here) or [X] Correspondence address below

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Signature	Charles Q Buckwalter	Date	6/24/98

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FEE TRANSMITTAL

Patent fees are subject to annual revision on October 1. These are the fees effective October 1, 1997. Small Entity payments must be supported by a small entity statement, otherwise large entity fees must be paid. See Forms PTO/SB/09-12. See 37 C.F.R. §§ 1.27 and 1.28.

TOTAL AMOUNT OF PAYMENT ($) 900

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	RIOJA
Examiner Name	
Group / Art Unit	
Attorney Docket No.	97-2301

METHOD OF PAYMENT (check one)

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

Deposit Account Number: 01-1000

Deposit Account Name: Aluminum Co. of America

☒ Charge Any Additional Fee Required Under 37 C.F.R. §§ 1.16 and 1.17

☐ Charge the Issue Fee Set in 37 C.F.R. § 1.18 at the Mailing of the Notice of Allowance

2. ☐ Payment Enclosed: ☐ Check ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	790	201	395	Utility filing fee	790
106	330	206	165	Design filing fee	
107	540	207	270	Plant filing fee	
108	790	208	395	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($) 790

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	25	-20** =	5	X	22	=	110
Independent Claims	2	- 3** =	0	X	82	=	—
Multiple Dependent					270	=	—

**or number previously paid, if greater; For Reissues, see below

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	22	203	11	Claims in excess of 20
102	82	202	41	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim, if not paid
109	82	209	41	** Reissue independent claims over original patent
110	22	210	11	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 110

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet.	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	400	216	200	Extension for reply within second month	
117	950	217	475	Extension for reply within third month	
118	1,510	218	755	Extension for reply within fourth month	
128	2,060	228	1,030	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,320	241	660	Petition to revive - unintentional	
142	1,320	242	660	Utility issue fee (or reissue)	
143	450	243	225	Design issue fee	
144	670	244	335	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	790	246	395	Filing a submission after final rejection (37 CFR 1.129(a))	
149	790	249	395	For each additional invention to be examined (37 CFR 1.129(b))	

Other fee (specify) ____________________

Other fee (specify) ____________________

* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($)

SUBMITTED BY				Complete (if applicable)	
Typed or Printed Name	CHARLES Q BUCKWALTER			Reg. Number	32969
Signature	Charles Q Buckwalter	Date	6/24/98	Deposit Account User ID	

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PATENT

ALUMINUM-COPPER-MAGNESIUM ALLOYS HAVING ANCILLARY ADDITIONS OF LITHIUM

BACKGROUND OF THE INVENTION

This invention relates to aluminum-copper-magnesium alloys having ancillary additions of lithium in order to decrease density while at the same time increasing strength, toughness, and especially fatigue crack growth resistance of the aluminum-copper-magnesium alloy. These alloys are useful in aerospace applications, for example.

It is generally well known in the aerospace industry that one of the most effective ways to reduce the weight of an aircraft is to reduce the density of aluminum alloys used in aircraft construction. This desire led to the addition of lithium, the lowest density metal element, to aluminum alloys. Aluminum Association ("AA") alloys, such as 2090 and 2091 contained about 2.0 wt % lithium, which translated into about a 7% weight savings over alloys containing no lithium. Another aluminum alloy, AA 8090 contained about 2.5 wt % lithium, which translated into an almost 10% weight savings over alloys without lithium.

Molten lithium, however, is a highly reactive and highly aggressive material, which is difficult to handle and which is also difficult to alloy with the base alloy. Because of its high reactivity, any moisture in the presence of the molten aluminum-lithium can cause explosions. In addition, because of its highly aggressive nature, special refractories must be used in casting the lithium alloys.

Because the propensity for explosions of molten aluminum-lithium is reduced as the weight percent of lithium is reduced, it is desired to reduce lithium levels. However, it is also desirable to maintain the properties of less density, greater strength and increased fatigue crack growth

resistance at the same time. Of course, it was known that reductions in the weight percent of lithium would result in less weight savings, but this tradeoff was made in order to reduce the difficulty of making the aluminum-lithium alloys.

United States Patent No. 5,455,003 discloses aluminum-copper-lithium alloys with improved cryogenic fracture toughness. Of major importance in cryogenic applications are high strength and high fracture toughness. These properties are obtained by artificially aging the aluminum alloy. However, this aging will have a detrimental effect on fatigue crack growth resistance. In damage tolerant applications in aircraft, fatigue crack growth resistance is very important. Better fatigue crack growth resistance means that cracks will grow slower, thus making airplanes much safer because small cracks can be detected before they achieve critical size for catastrophic propagation. Furthermore, slower crack growth can have an economic benefit due to the fact that longer inspection intervals can be utilized.

What is needed, therefore, is an aluminum alloy useful for, among other things, damage tolerant applications in aircraft which has not only low density, high strength and good fracture toughness, but also excellent fatigue crack growth resistance.

SUMMARY OF THE INVENTION

The aluminum alloy of the invention has met or exceeded the above-mentioned needs as well as others. The aluminum alloy comprises up to about 4.5 wt % copper; from about 0.6 to 6.0 wt % magnesium; and from about 0.01 to 1.0 wt % lithium. It has been found, quite surprisingly and unexpectedly, that the ancillary additions of low levels of lithium to aluminum-copper-magnesium alloys provided a high strength, low density material that exhibited good fracture toughness and improved fatigue crack growth resistance over prior art aluminum-copper-magnesium alloys.

BRIEF DESCRIPTION OF THE DRAWINGS

A full understanding of the invention can be gained from the following detailed description of the invention when read in conjunction with the accompanying drawings in which:

Figure 1A is a graph showing the composition space covering aluminum-copper-magnesium alloys with ancillary lithium additions.

Figure 1B is a chart showing the tensile yield strength of various specimens made from aluminum alloys containing aluminum-copper-magnesium alloys designated Alloy A, Alloy B, Alloy C and Alloy D after being subjected to different aging conditions.

Figure 2 is a bar graph showing the improvement in specific strength for some of the specimens shown in Figure 1.

Figure 3 is a graph showing the typical representation of fatigue crack growth performance rate da/dn (*in/cycle*) and how it changes with performance improvements.

Figure 4 is a graph showing the fatigue crack growth curves for (1) Alloy A-T3 plate; (2) Alloy C-T3 plate; and (3) Alloy D-T3 plate.

Figure 5 is a graph showing the fatigue crack growth curves for (1) Alloy A-T39 plate; (2) Alloy C-T39 plate; and (3) Alloy D-T39 plate.

Figure 6 is a graph showing the fatigue growth curves for (1) Alloy A-T8 plate; (2) Alloy C-T8 plate; and (3) Alloy D-T8 plate.

Figure 7 is a bar graph showing the percentage change in da/dn at $\Delta K = 10$ Ksi $(in)^{1/2}$.

Figure 8 is a graph showing the fracture toughness R-curves of Alloy A-T3 and Alloy C-T3.

Figure 9 is a graph showing the fracture toughness R-curves of Alloy A-T39, Alloy C-T39 and Alloy D-T39 plate.

DETAILED DESCRIPTION

For the description of alloy compositions that follow, all references are to weight percentages (*wt* %) unless otherwise indicated. When referring to any numerical range of values, such ranges are to be understood to include each and every number and/or fraction between the stated range minimum and maximum. A range of about 0.01 to 0.99 wt % lithium, for example, would include all intermediate values of about 0.02, 0.03, 0.04 and 0.1 wt % all the way up to and including .97, .98 and .9895 wt % lithium. The same applies to the other elemental ranges set forth below. The term *"substantially free"* means having no significant amount of that component purposely added to the alloy composition, it being understood that trace amounts of incidental elements and/or impurities may find their way into a desired end product.

As used herein, the term *"damage tolerant aircraft part"* means any aircraft or aerospace part which is designed to ensure that its crack growth life is greater than any accumulation of service loads which could drive a crack to a critical size resulting in catastrophic failure. Damage tolerance design is used for most of the primary structure in a transport category airframe, including but not limited to fuselage panels, wing boxes, horizontal and vertical stabilizer boxes, pressure bulkheads, and door and window frames. In inspectable areas, damage tolerance is typically achieved by redundant designs for which the inspection intervals are set to provide at least two inspections per number of flights or flight hours it would take a visually detectable crack to grow to its critical size.

The present invention relates to an aluminum-copper-magnesium alloy having ancillary additions of lithium. In accordance with the invention, a wrought aluminum-copper-magnesium-lithium alloy is provided which has improved strength, fracture toughness and fatigue crack growth

resistance over prior art aluminum-copper-magnesium alloys. The alloys of the present invention are especially useful for damage tolerant aircraft parts, such as lower wing sections, because of the surprising and unexpected increase in fatigue crack growth resistance over prior art aluminum-copper-magnesium alloys. Because of the addition of low levels of lithium additions, the problems of higher (*i.e., over 1.5 wt % lithium*) additions of lithium, such as explosions of the molten metal, are reduced or eliminated.

The compositional ranges of the main alloying elements (*copper, magnesium and lithium*) of the improved alloy of the invention are broadly defined as follows: (1) up to 4.5 wt % copper; (2) from about .6 to 6.0 wt % magnesium; and (3) from about 0.01 to 0.99 wt % of lithium. The balance of the aluminum alloy of the invention contains aluminum and incidental impurities.

In addition to aluminum, copper, magnesium and lithium, the alloys of the present invention can contain dispersoids selected from the group consisting of chromium, vanadium, titanium and zirconium and mixtures thereof in the range of about 0.0 to 0.6 wt % and/or dispersoids such as manganese, nickel, iron, hafnium and scandium and mixtures thereof in the range of 0 to 1 wt %. Other alloying elements, such as zinc, silver and silicon and mixtures thereof in amounts up to about 2.0 wt % can also be added.

The copper is added to increase the strength of the aluminum base alloy. Care must be taken, however, to not add too much copper since the corrosion resistance can be reduced. Also, copper additions beyond maximum solubility can lead to low fracture toughness and low damage tolerance.

The magnesium is added to provide strength and reduce density. Care should be taken, however, to not add too much magnesium since magnesium additions beyond maximum solubility will lead to low fracture toughness and low damage tolerance.

The lithium is added to reduce density and to increase strength. Care should be taken, however, in not adding too much lithium since exceeding the maximum solubility will lead to low fracture toughness and low damage tolerances. Lithium additions in amounts of about 1.5 wt % and above result in the formation of the δ' (*"delta prime"*) phase with composition of Al_3Li. The presence of this phase, Al_3Li, is to be avoided in the alloys of the present invention.

The interaction of lithium atoms in supersaturated solid solution, with atoms of magnesium and/or copper appear to give rise to the formation of clusters of atoms of solute. This behavior is observed by the appearance of diffuse scatter in electron diffraction images. This behavior, which was not expected and is surprising, is apparently responsible for the improvements in fatigue performance of the alloys of the invention, which will be discussed below.

It has been found, quite unexpectedly and surprisingly, that the combination of lower copper levels, higher magnesium levels and lower levels of lithium give a surprisingly strong, less dense aluminum alloy which has superior fatigue crack growth resistance. Fatigue crack growth resistance is a critical property for damage tolerant aircraft parts, such as fuselage sections and lower wing sections. As is known, these parts of an aircraft are subject to cyclical stresses, such as the fuselage skin which is expanded and contracted upon pressurization and depressurization of the aircraft cabin and the lower wing skin which experiences tensile stresses in flight and compressive stresses while the aircraft is on the ground. Improved fatigue crack growth resistance means cracks will grow and reach their critical dimension more slowly. This allows longer inspection intervals to be used, thus reducing aircraft operating cost. Alternatively, the applied stress could be raised while keeping the same inspection interval, thereby reducing aircraft weight.

Returning now to a discussion of the alloy composition of the invention, it should be noted that the copper and magnesium in the compositional ranges set forth above will be soluble in the alloy. This is important in that atoms of the alloying elements in solid solution or forming clusters translate to increased fatigue crack growth resistance, which is, as was mentioned above, a critical property for damage tolerant aircraft parts.

Referring now to Figure 1A, the broad, preferred, more preferred and most preferred ranges for the copper and magnesium contents of the aluminum alloy of the invention will be discussed. For all of these copper and magnesium ranges, the range of the lithium content is from about 0.01 to 0.99 wt %. A benefit has been observed when the lithium concentration is above 0.25 and even 0.35 and up to 0.95. The lithium concentration will vary depending on the desired level of improved performance of the wrought product. The combination of copper, magnesium and lithium needs to be carefully considered as to not exceed maximum solubility. The following composition ranges were selected using a combination of phase diagram data from thermodynamic equilibrium and experimental results.

Turning now to Figure 1A, it can be seen that the broad ranges for copper and magnesium fall within a closed area on a graph with wt % copper on the x-axis and wt % magnesium on the y-axis, the closed area being bounded by generally straight lines joining the following points:

POINT A = 0 Cu. 0.6 Mg
POINT B = 4.5 Cu, 0.6 Mg
POINT C = 4.5 Cu, 6.0 Mg
POINT D = 0 Cu, 6.0 Mg
and back to POINT A.

The preferred ranges for copper and magnesium are defined by a closed area on a graph with wt % copper on the x-axis and

wt % magnesium on the y-axis, the closed area being bounded by generally straight lines joining the following points:

POINT A = 0 Cu, 0.6 Mg
POINT B = 4.5 Cu, 0.6 Mg
POINT E = 4.5 Cu, 2.3 Mg
POINT F = 2.0 Cu, 6.0 Mg
POINT D = 0 Cu, 6.0 Mg
and back to POINT A.

The more preferred ranges for copper and magnesium are defined by a closed area on a graph with wt % copper on the x-axis and wt % magnesium on the y-axis, the closed area being bounded by generally straight lines joining the following points:

POINT A - 0 Cu, 0.6 Mg
POINT B = 4.5 Cu, 0.6 Mg
POINT G = 1.5 Cu, 6.0 Mg
POINT D = 0 Cu, 6.0 Mg
and back to POINT A.

Finally, the most preferred ranges for copper and magnesium are defined by a closed area on a graph with wt % copper on the x-axis and wt % magnesium on the y-axis, the closed area being bounded by generally straight lines joining the following points:

POINT A = 0 Cu, 0.6 Mg
POINT B = 4.5 Cu, 0.6 Mg
POINT H = 4.5 Cu, 2.0 Mg
POINT I = 0 Cu, 2.0 Mg
and back to POINT A.

It will be appreciated that the equation for straight line 1 on Figure 1A (*between Points E and F*) can be expressed as follows:

$$Cu=\frac{-2.5}{3.7}(Mg-6)+2$$

and the equation for straight line 2 (*between Points B and G*) can be expressed as the following equation:

$$Cu = \frac{-3}{5.4}(Mg - 6) + 1.5$$

The following example sets forth alloys and resulting wrought products made in accordance with the invention.

EXAMPLE

An ingot of an aluminum-copper-magnesium alloy having the following composition was cast:

INGOT NO. 1

Si	Fe	Cu	Mn	Mg	Zn	Zr
0.03	0.03	3.24	0.58	1.32	-0-	0.11

(*Remainder is aluminum and incidental impurities.*)

Material fabricated from this ingot will be designated Alloy A hereinafter in this Example.

After this, the remaining molten metal was re-alloyed (*i.e., alloying again an alloy already made*) by adding 0.25% lithium to create a target addition of 0.25 wt % lithium. A second ingot was then cast having the following composition:

INGOT NO. 2

Li	Si	Fe	Cu	Mn	Mg	Zn	Zr
0.19	0.03	0.04	3.41	0.61	1.28	-0-	0.1

(*Remainder is aluminum and incidental impurities.*)

Material fabricated from this ingot will be designated Alloy B hereinafter in this Example.

Ingot No. 3 was created by re-alloying the remaining molten metal after casting Ingot No. 2 and then adding another 0.25 wt % lithium to create a total target addition of 0.50 wt % lithium. Ingot No. 3 had the following composition:

INGOT NO. 3

Li	Si	Fe	Cu	Mn	Mg	Zn	Zr
0.35	0.04	0.04	3.37	0.6	1.2	-0-	0.11

(Remainder is aluminum and incidental impurities.)

Material fabricated from this ingot will be designated Alloy C hereinafter in this Example.

Ingot No. 4 was created by re-alloying the remaining molten metal after casting Ingot No. 3 and then adding another 0.25 wt % lithium to create a total target addition of 0.75 wt % lithium. A fourth ingot was cast having the following composition:

INGOT NO. 4

Li	Si	Fe	Cu	Mn	Mg	Zn	Zr
0.74	0.02	0.03	3.34	0.56	1.35	0.01	0.12

(Remainder is aluminum and incidental impurities.)

Material fabricated from this ingot will be designated Alloy D hereinafter in this Example.

The four ingots were stress relieved and homogenized. The ingots were then subjected to a standard presoak treatment after which the ingots were machine scalped. The scalped ingots were then hot rolled into four (4) separate 0.7 inch gauge plates using hot rolling practices typical of *2XXX* alloys.

After the four (4) separate plates were produced, a section of each of the plates was removed. Each of the four (4) sections were (a) solution heat treated; (b) quenched; and (c) stretched 1.5%. After this, eight (8) tensile strength test samples were produced from each of the

treated four (4) sections, making a total of thirty-two (32) tensile strength test samples. One tensile strength test sample from each group of eight (8) (*there being a total of four (4) plates in each group*) was each subject to eight (8) different aging conditions, as described in the legend of Figure 1. After this, tensile yield strength tests were performed, with the results being shown in Figure 1B. It will be seen that the alloys having lithium additions exhibited greater strength than those without lithium, while at the same time exhibiting thermal stability.

After this, the remainder of three of the four plates (*i.e., Ingot No. 1 plate, Ingot No. 3 plate and Ingot No. 4 plate*) was each cut into thirds (*1/3rds*), to form pieces 1, 2 and 3 for each plate, or a total of 9 pieces. Piece 1 of all three plates were (a) solution heat treated; (b) quenched; (c) stretched 1 1/2%; and (d) aged to T8 temper by aging it 24 hours @ 350°F. These pieces were designated Alloy A-T8; Alloy C-T8; and Alloy D-T8. Piece 2 of all three plates were (a) solution heat treated; (b) quenched; (c) stretched 1 1/2%; and (d) naturally aged to T3 temper. These pieces were designated Alloy A-T3; Alloy C-T3; and Alloy D-T3. Finally, Piece 3 of all three plates were (a) solution heat treated; (b) quenched; (c) cold rolled 9%; (d) stretched 1 1/2%; and (e) naturally aged. These pieces were designated Alloy A-T39; Alloy C-T39; and Alloy D-T39. It was these pieces which provided the material for all of the further testing which will be reported herein.

Referring now to Figure 2, the tensile yield strength divided by density for a testing portion of each of the nine (9) pieces produced above is shown. It can be seen that improvements in the tensile yield strength to density ratio were found for ancillary lithium additions.

Referring now to Figures 3-7, the key property of fatigue crack growth resistance will now be discussed. Figure 3 is a graph showing the typical representation of

fatigue crack growth performance and how improvements therein can be shown. The x-axis of the graph shows the applied driving force for fatigue crack propagation in terms of the stress intensity factor range, ΔK, which is a function of applied stress, crack length and part geometry. The y-axis of the graph shows the material's resistance to the applied driving force and is given in terms of the rate a which a crack propagates, da/dn in inch/cycle. Both ΔK and da/dn are presented on logarithmic scales as is customary. Each curve represents a different alloy with the alloy having the curve to the right exhibiting improved fatigue crack growth resistance with respect to the alloy having the curve to the left. This is because the alloy having the curve to the right exhibits a slower crack propagation rate for a given ΔK which represents the driving force for crack propagation.

Turning to Figures 4-6, it can be seen, that based on the criteria discussed with respect to Figure 3, the addition of lithium substantially increases the fatigue crack growth resistance in the respective alloys in the T3 and T39 conditions. The fatigue crack rates for crack driving forces of ΔK equal to 10 Ksi $(in)^{1/2}$ are summarized in Figure 7. The percentage improvement in fatigue crack growth resistance (*i.e., percentage reduction in fatigue crack growth rates*) is given at the top of the graph. Alloy C-T3 and Alloy D-T3 show improvements of 27% and 26%, respectively over Alloy A-T3 (*no lithium additions*). The percentage improvements in fatigue crack growth resistance of Alloy C-T39 and Alloy D-T39 over Alloy A-T39 (*no lithium additions*) was 67% and 47% respectively.

With regard to the T8 alloys, it can be seen that the lithium additions do not improve the fatigue crack growth resistance. In the case of artificially aged alloys, aged to peak strength, the only advantage of lithium additions is in terms of additional strength and lower density.

Figures 8 and 9 show the fracture toughness R-curves for the T3 and T39 tempers, respectively. The R-curve is a measure of resistance to fracture (K_R) versus stable crack extension (Δaeff). In addition, the following table shows single-point measurements of fracture toughness for Alloys A, C and D in the T3, T39 and T8 tempers in terms of K_{R25}, which is the crack extension resistance, K_R, on the R-curve corresponding to the 25% secant offset of the test record of load versus crack-opening displacement (COD), and Kq, which is the crack extension resistance corresponding to the 5% secant offset of the test record of load versus COD. K_{R25} is an appropriate measure of fracture toughness for moderate strength, high toughness alloy/tempers such as T3 and T39, while Kq is appropriate for higher strength, lower toughness alloy/tempers such as T8.

TABLE

Strength And Toughness Measurements
(Tensile Longitudinal Properties - Toughness Orientation L-T)

Alloy/Temper	TYS (Ksi)	UTS (Ksi)	Elongation (%)	Kq (Ksi in$^{1/2}$)	KR 25 (Ksi in$^{1/2}$)
Alloy A-T3	47.7	65.6	18.6	-	97.9
Alloy C-T3	51.4	69.8	17.1	-	107.8
Alloy D-T3	51.1	70.6	17.5	-	NOT TESTED
Alloy A-T39	61.2	67.3	11.4	-	88.8
Alloy C-T39	63.3	70.7	9.3	-	91.5
Alloy D-T39	65.7	70.5	9.9	-	97.5
Alloy A-T8	63.7	69.7	12.1	32.4	-
Alloy C-T8	65.9	71.9	11.7	38.7	-
Alloy D-T8	67.8	73.8	10.7	38.9	-

It will be appreciated that fracture toughness is somewhat improved by the lithium additions. Moreover, it should be noted that lithium additions yielded improved toughness at a higher strength level. Therefore, the strength/toughness relationship was significantly improved.

This was unexpected because lithium additions are well known to decrease fracture toughness. However, it should be noted that the lithium additions yielded higher strength. Therefore, the strength/toughness relationship was improved.

While specific embodiments of the invention have been disclosed, it will be appreciated by those skilled in the art that various modifications and alterations to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention which is to be given the full breadth of the appended claims and any and all equivalents thereof.

WHAT IS CLAIMED IS:

1. An aluminum alloy comprising up to about 4.5 wt % copper, from about 0.6 to 6.0 wt % magnesium and from about 0.01 to 0.99 wt % lithium.

2. The aluminum alloy of Claim 1, wherein said lithium content is from about 0.25 to 0.99 wt %.

3. The aluminum alloy of Claim 2, wherein said lithium content is from about 0.25 to 0.95 wt %.

4. The aluminum alloy of Claim 3, wherein said lithium content is from about 0.35 to 0.95 wt %.

5. The aluminum alloy of Claim 1, including a dispersoid selected from the group consisting of chromium, vanadium, titanium and zirconium and mixtures thereof in the amount of from about 0.0 to 0.6 wt %.

6. The aluminum alloy of Claim 1, including a dispersoid selected from the group consisting of manganese, nickel, iron, hafnium, scandium and mixtures thereof in the amount of from about 0.0 to 1.0 wt %.

7. The aluminum alloy of Claim 1, including a first dispersoid selected from the group consisting of chromium, vanadium, titanium, zirconium and mixtures thereof in the amount of from about 0.0 to 0.6 wt % and a second dispersoid selected from the group consisting of manganese, nickel, iron, hafnium, scandium and mixtures thereof in the amount of from about 0.04 to 1.0 wt %.

8. The aluminum alloy of Claim 1, including other alloying elements selected from the group consisting of zinc, silver, silicon and mixtures thereof in the amount of from about 0.0 to 2.0 wt %.

9. A damage tolerant aircraft part made from the alloy of Claim 1.

10. A fuselage section made from the alloy of Claim 1.

11. A lower wing section made from the alloy of Claim 1.

12. An aluminum alloy comprising copper, magnesium and lithium, the lithium content being from about 0.01 to 0.99 wt % and the copper and magnesium weight percent values falling within a closed area on a graph with wt % copper on the x-axis and wt % magnesium on the y-axis, said closed area being bounded by generally straight lines joining the following points:

POINT 1 = 0 Cu. 0.6 Mg
POINT 2 = 4.5 Cu, 0.6 Mg
POINT 3 = 4.5 Cu, 6.0 Mg
POINT 4 = 0 Cu, 6.0 Mg
and back to POINT 1.

13. The aluminum alloy of Claim 12, wherein the copper and magnesium weight percent values fall within a closed area on a graph with wt % copper on the x-axis and

wt % magnesium on the y-axis, said closed area being bounded by generally straight lines joining the following points:

POINT 1 = 0 Cu, 0.6 Mg
POINT 2 = 4.5 Cu, 0.6 Mg
POINT 3 = 4.5 Cu, 2.3 Mg
POINT 4 = 2.0 Cu, 6.0 Mg
POINT 5 = 0 Cu, 6.0 Mg
and back to POINT 1.

14. The aluminum alloy of Claim 12, wherein the copper and magnesium weight percent values fall within a closed area on a graph with wt % copper on the x-axis and wt % magnesium on the y-axis, said closed area being bounded by generally straight lines joining the following points:

POINT 1 = 0 Cu. 0.6 Mg
POINT 2 = 4.5 Cu, 0.6 Mg
POINT 3 = 1.5 Cu, 6.0 Mg
POINT 4 = 0 Cu, 6.0 Mg
and back to POINT 1.

15. The aluminum alloy of Claim 12, wherein the copper and magnesium weight percent values fall within a closed area on a graph with wt % copper on the x-axis and wt % magnesium on the y-axis, said closed area being bounded by generally straight lines joining the following points:

POINT 1 = 0 Cu. 0.6 Mg
POINT 2 = 4.5 Cu, 0.6 Mg
POINT 3 = 4.5 Cu, 2.0 Mg
POINT 4 = 0 Cu, 2.0 Mg
and back to POINT 1.

16. The aluminum alloy of Claim 12, wherein said lithium content is from about 0.25 to 0.99 wt %.

17. The aluminum alloy of Claim 16, wherein said lithium content is from about 0.25 to 0.95 wt %.

18. The aluminum alloy of Claim 17, wherein said lithium content is from about 0.35 to 0.95 wt %.

19. The aluminum alloy of Claim 12, including a dispersoid selected from the group consisting of chromium, vanadium, titanium and zirconium and mixtures thereof in the amount of from about 0.0 to 0.6 wt %.

20. The aluminum alloy of Claim 12, including a dispersoid selected from the group consisting of manganese, nickel, iron, hafnium, scandium and mixtures thereof in the amount of from about 0.0 to 1.0 wt %.

21. The aluminum alloy of Claim 12, including a first dispersoid selected from the group consisting of chromium, vanadium, titanium, zirconium and mixtures thereof in the amount of from about 0.0 to 0.6 wt % and a second dispersoid selected from the group consisting of manganese, nickel, iron, hafnium, scandium and mixtures thereof in the amount of from about 0.04 to 1.0 wt %.

22. The aluminum alloy of Claim 12, including other alloying elements selected from the group consisting of zinc, silver, silicon and mixtures thereof in the amount of from about 0.0 to 2.0 wt %.

23. A damage tolerant aircraft part made from the alloy of Claim 12.

24. A fuselage section made from the alloy of Claim 12.

25. A lower wing section made from the alloy of Claim 12.

ABSTRACT OF THE DISCLOSURE

An aluminum-copper-magnesium alloy having ancillary additions of lithium. The alloy composition includes up to about 4.5 wt % copper; from about .6 to 6.0 wt % magnesium; and from about 0.01 to 1.0 wt % lithium.

Composition Space Covering Al-Cu-Mg Alloys
With Ancillary Li Additions

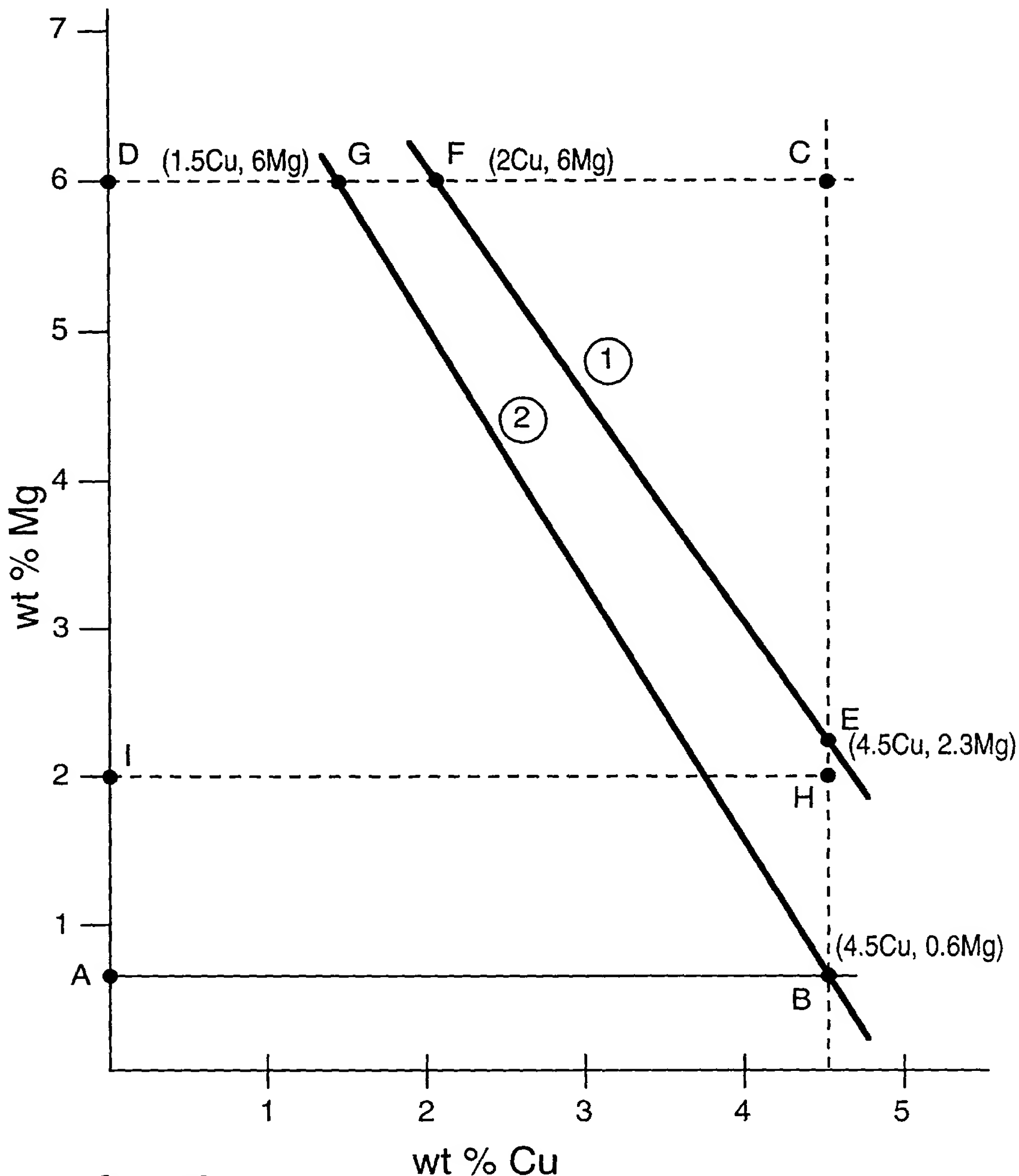
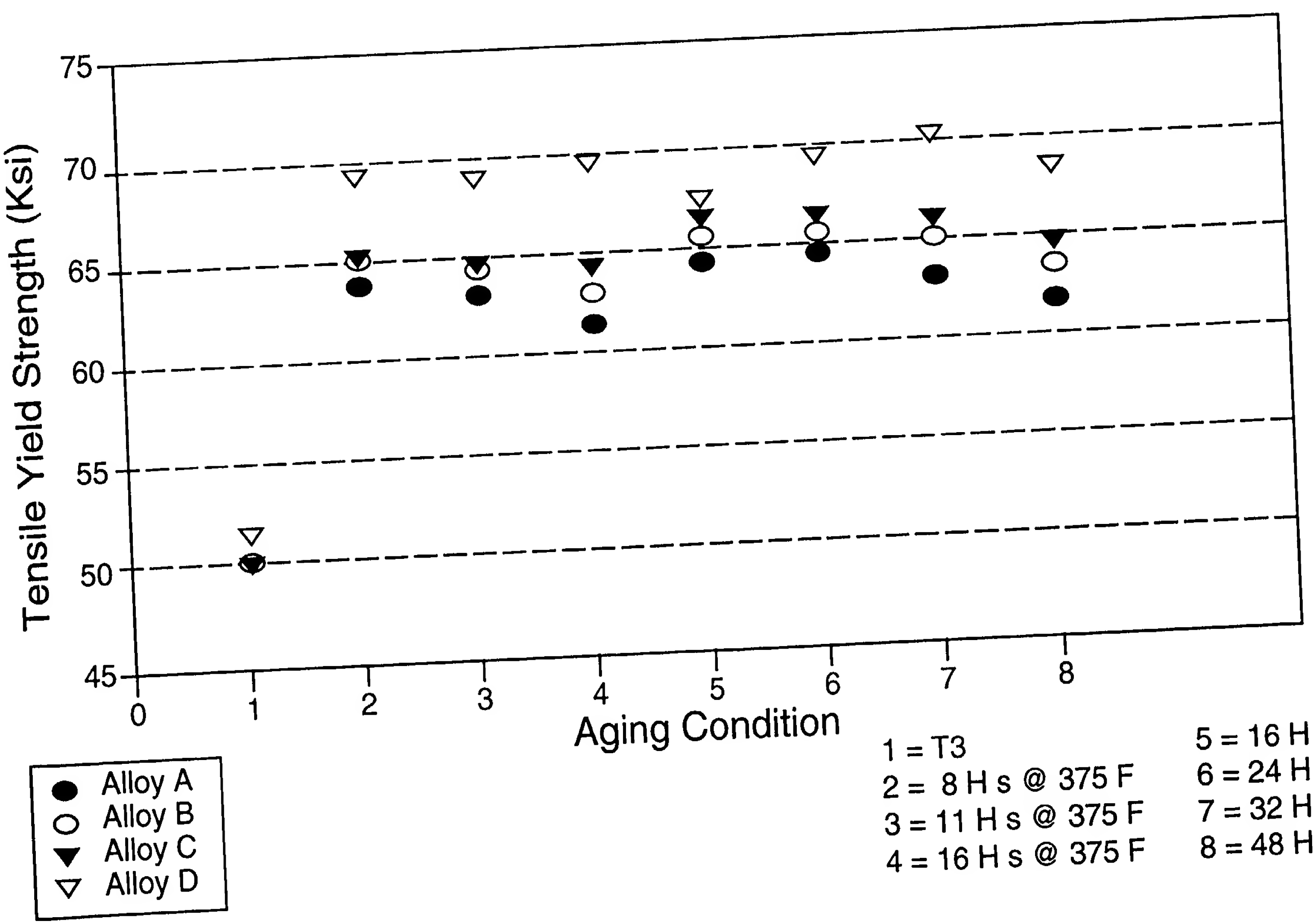
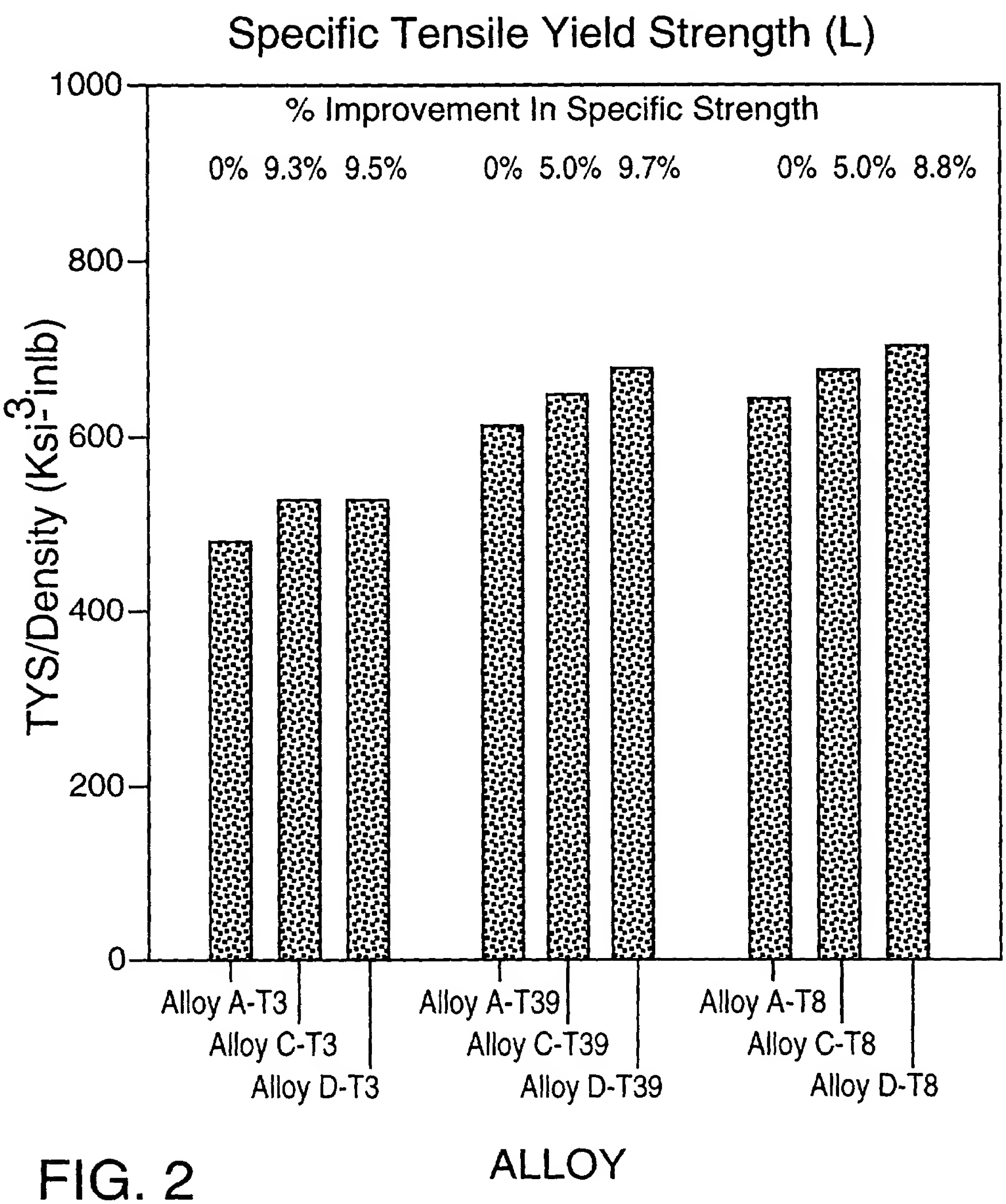


FIG. 1A



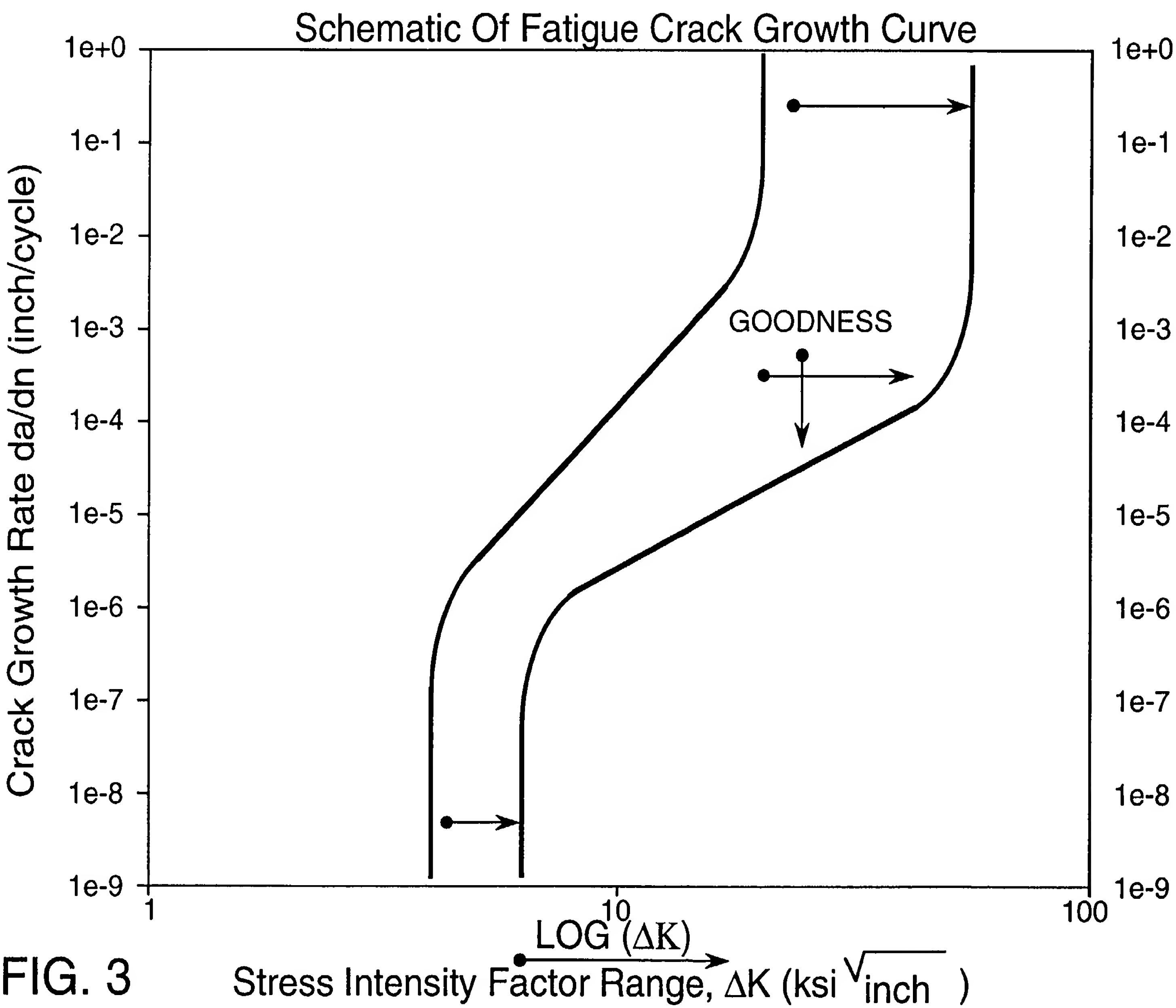
1 = T3
2 = 8 H s @ 375 F
3 = 11 H s @ 375 F
4 = 16 H s @ 375 F
5 = 16 H s @ 350 F
6 = 24 H s @ 350 F
7 = 32 H s @ 350 F
8 = 48 H s @ 350 F

FIG. 1B



Specific Tensile Yield Strength (L)
% Improvement In Specific Strength
0% 9.3% 9.5%
0% 5.0% 9.7%
0% 5.0% 8.8%
TYS/Density (Ksi-in³/lb)
1000
800
600
400
200
0
Alloy A-T3
Alloy C-T3
Alloy D-T3
Alloy A-T39
Alloy C-T39
Alloy D-T39
Alloy A-T8
Alloy C-T8
Alloy D-T8
ALLOY

FIG. 2



Schematic Of Fatigue Crack Growth Curve
Crack Growth Rate da/dn (inch/cycle)
1e+0
1e-1
1e-2
1e-3
1e-4
1e-5
1e-6
1e-7
1e-8
1e-9
GOODNESS
1
10
100
LOG10 (ΔK)
Stress Intensity Factor Range, ΔK (ksi √inch)

FIG. 3

Fatigue Crack Growth Curves Of Alloy A-T3, Alloy C-T3, Alloy D-T3

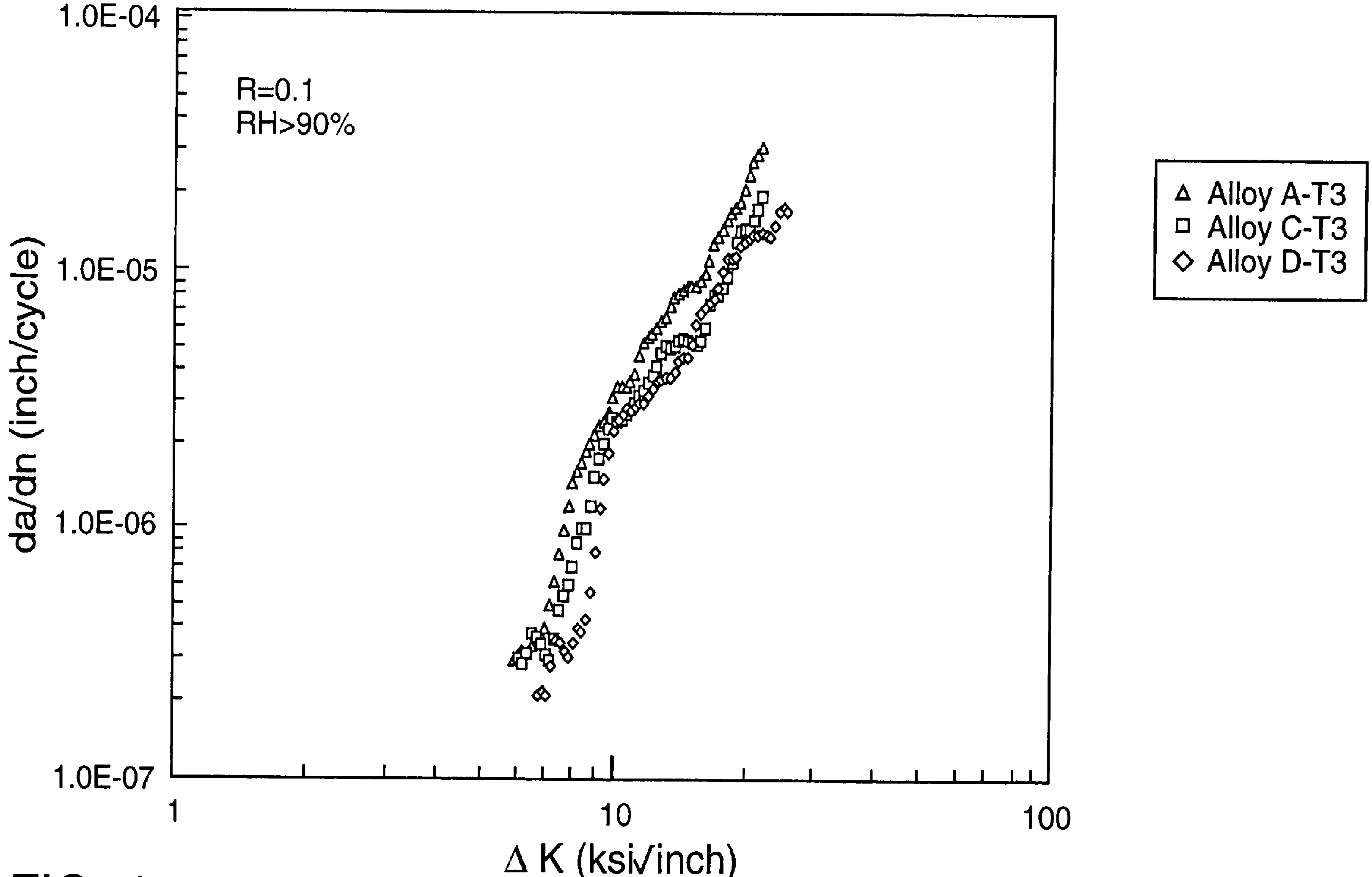


FIG. 4

Fatigue Crack Growth Curves Of Alloy A-T39, Alloy C-T39, Alloy D-T39

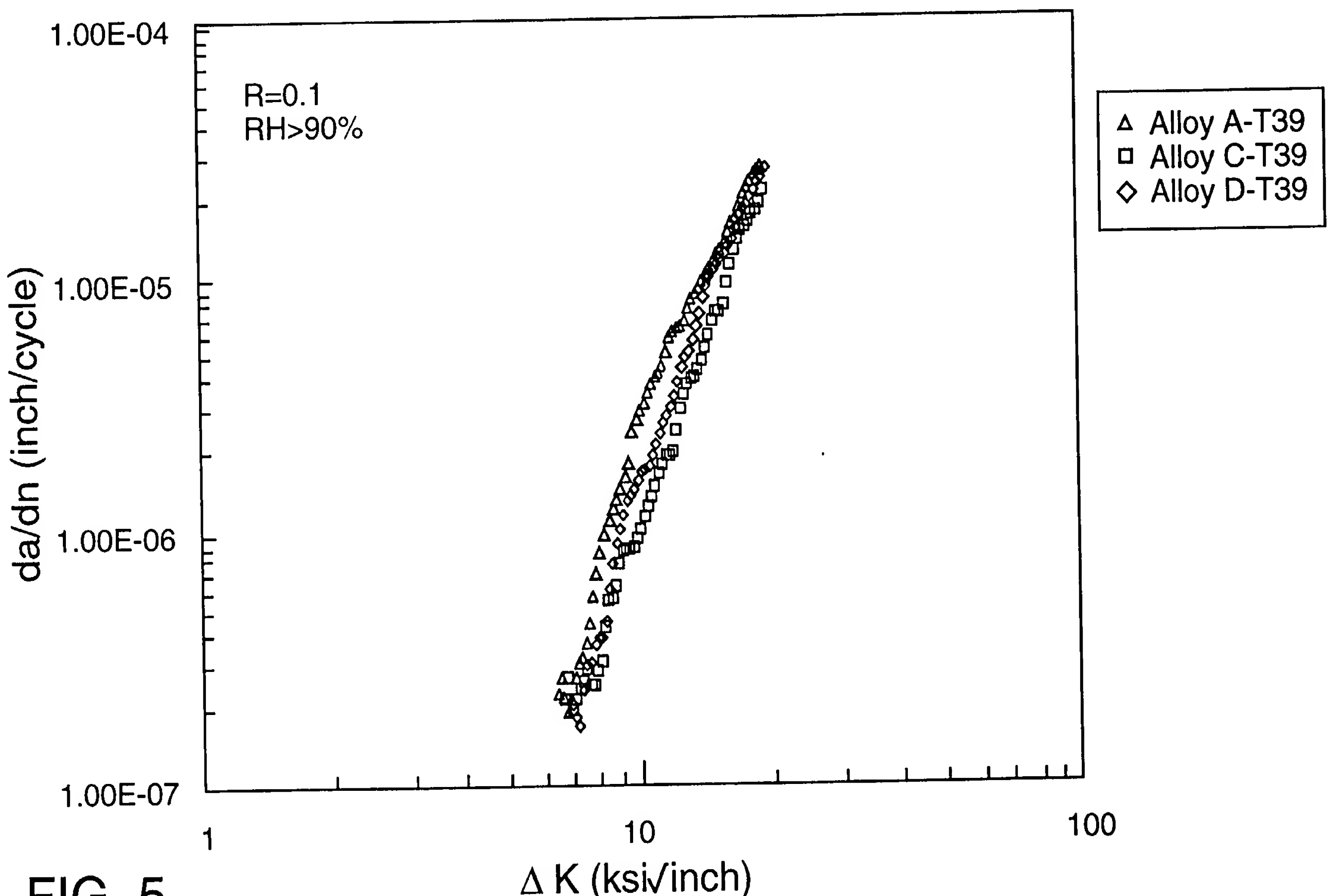
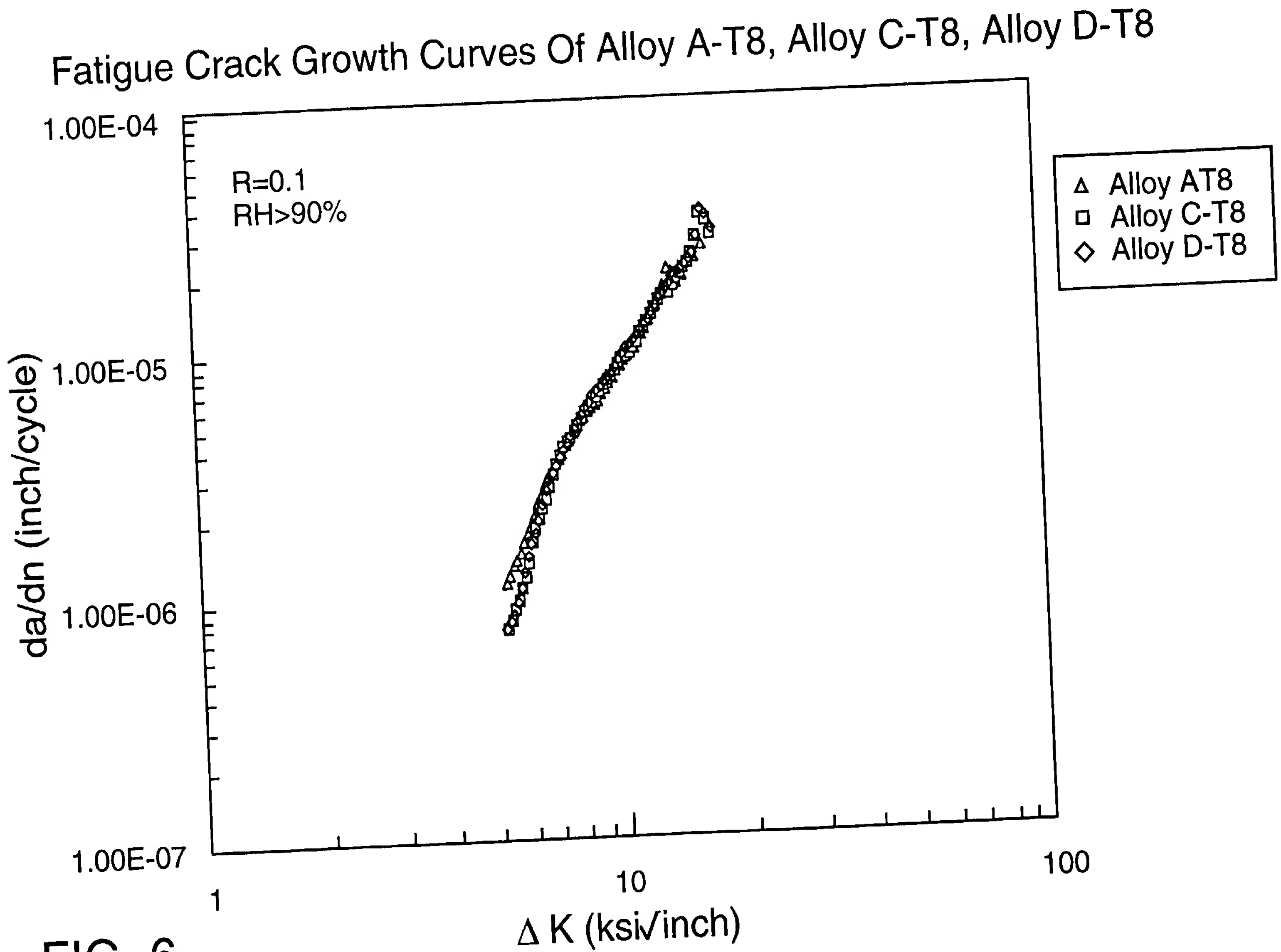


FIG. 5



Fatigue Crack Growth Curves Of Alloy A-T8, Alloy C-T8, Alloy D-T8
da/dn (inch/cycle)
1.00E-04
1.00E-05
1.00E-06
1.00E-07
R=0.1
RH>90%
Alloy AT8
Alloy C-T8
Alloy D-T8
1
10
100
Δ K (ksi√inch)

FIG. 6

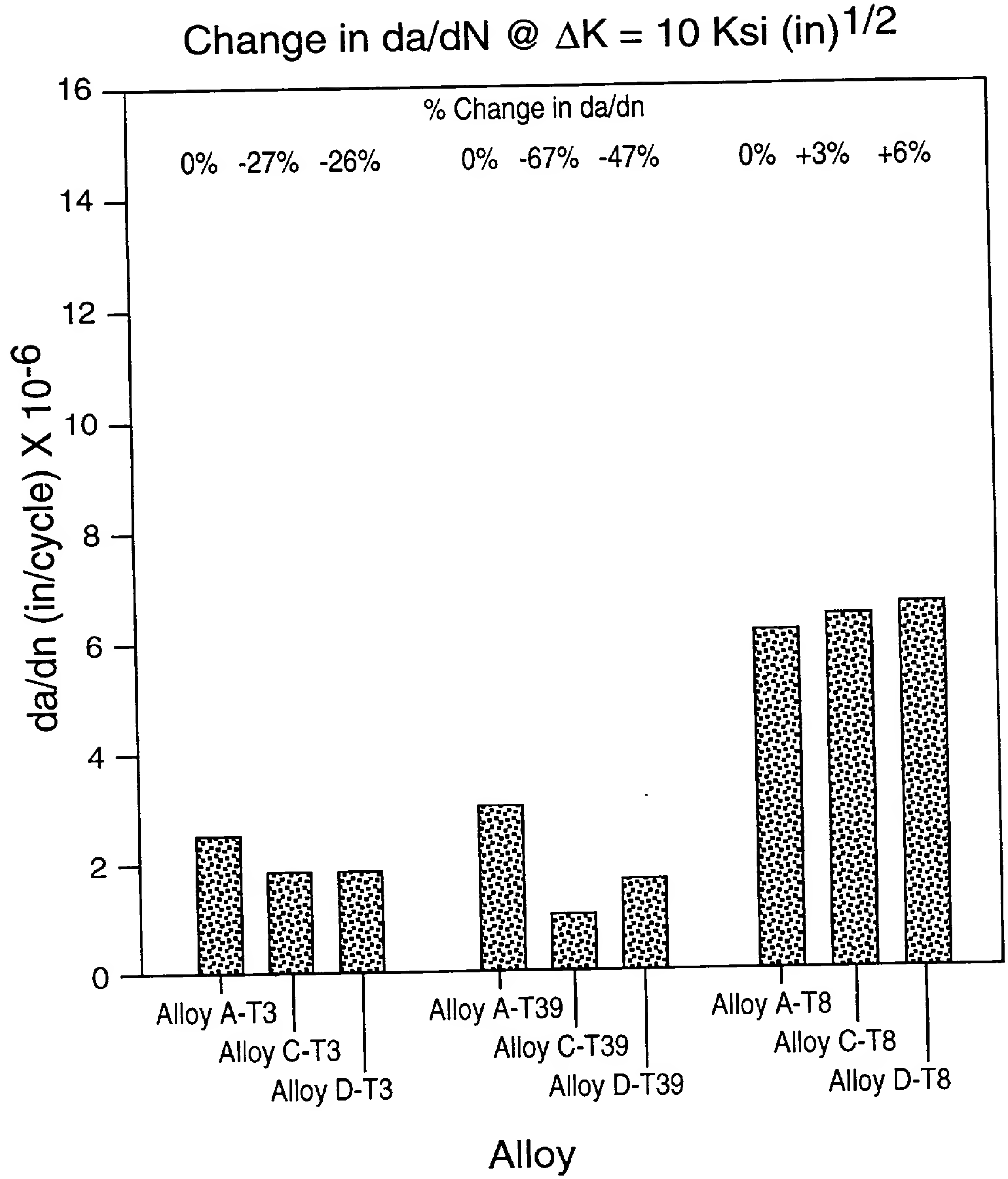
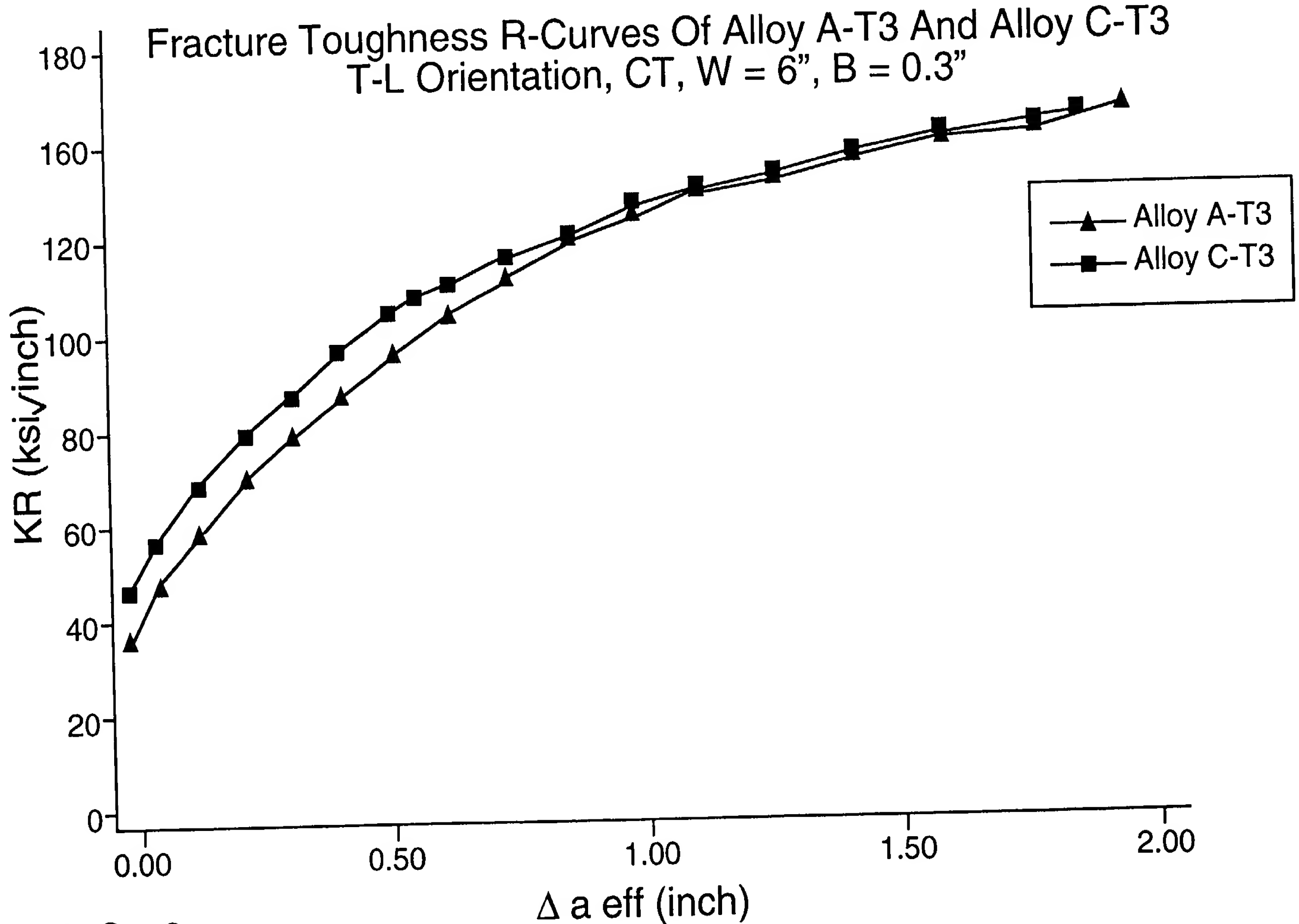

Change in da/dN @ ΔK = 10 Ksi (in)1/2
% Change in da/dn
0% -27% -26% 0% -67% -47% 0% +3% +6%
16
14
12
10
8
6
4
2
0
da/dn (in/cycle) X 10-6
Alloy A-T3
Alloy C-T3
Alloy D-T3
Alloy A-T39
Alloy C-T39
Alloy D-T39
Alloy A-T8
Alloy C-T8
Alloy D-T8
Alloy

FIG. 7



Fracture Toughness R-Curves Of Alloy A-T3 And Alloy C-T3
T-L Orientation, CT, W = 6", B = 0.3"
KR (ksi√inch)
180
160
120
100
80
60
40
20
0
0.00
0.50
1.00
1.50
2.00
Δ a eff (inch)
Alloy A-T3
Alloy C-T3

FIG. 8

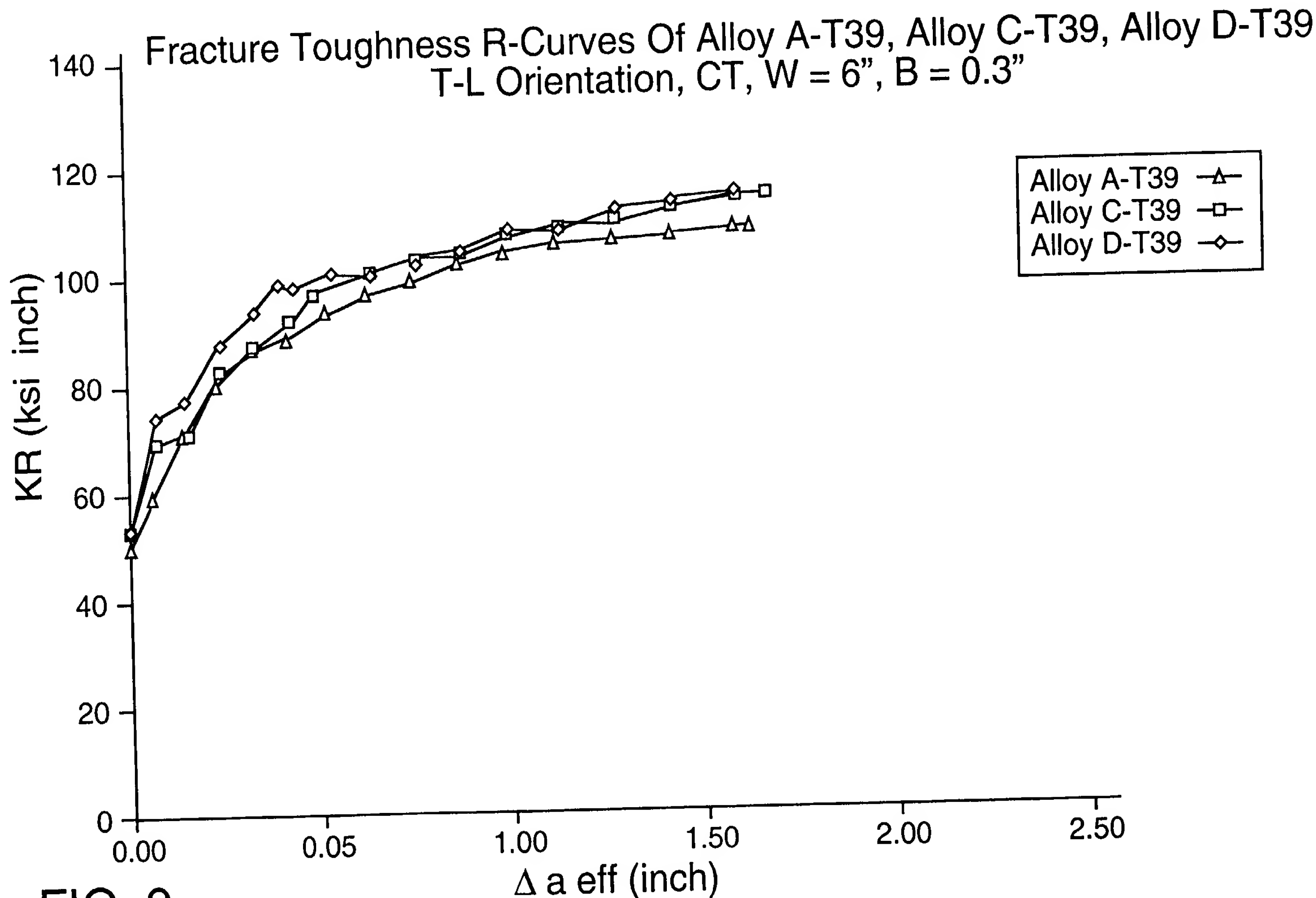

Fracture Toughness R-Curves Of Alloy A-T39, Alloy C-T39, Alloy D-T39
T-L Orientation, CT, W = 6", B = 0.3"
KR (ksi inch)
140
120
100
80
60
40
20
0
0.00
0.05
1.00
1.50
2.00
2.50
Δ a eff (inch)
Alloy A-T39
Alloy C-T39
Alloy D-T39

FIG. 9

DECLARATION FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **Aluminum-Copper-Magnesium Alloys Having Ancillary Additions of Lithium**,

the specification of which ■ is attached hereto
☐ was filed on ______________ as Application Serial No. ______________
and was amended on ______________ (*if applicable*).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s) | Priority Claimed

			Priority Claimed	
(Number)	*(Country)*	*(Day/Month/Year Filed)*	Yes	No
(Number)	*(Country)*	*(Day/Month/Year Filed)*	Yes	No

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

(Appln. Serial No.)	*(Filing Date)*	*(Status—patented, pending, abandoned)*
(Appln. Serial No.)	*(Filing Date)*	*(Status—patented, pending, abandoned)*

I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:
Tracey D. Beiriger (Reg. No. 37402), Charles Q. Buckwalter (Reg. No. 32969), Glenn E. Klepac (Reg. No. 26474), Edward L. Levine (Reg. No. 28097),David W. Pearce-Smith (Reg. No. 31285),Gary P. Topolosky (Reg. No. 31888), Thomas R. Trempus (Reg. No. 29708)

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Aluminum Company of America
Alcoa Technical Center
100 Technical Drive
Alcoa Center, PA 15069-0001

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under §1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor Roberto J. Rioja

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Inventor's signature ____________________ Date ____________

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